THREE-LINE SCANNER FOR LARGE-SCALE MAPPING

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ABSTRACT

This paper introduces a high-resolution helicopter-borne three-line scanner (TLS) for large-scale mapping. Since a high-performance stabilizer for the TLS camera absorbs the vibration of the aircraft and stabilizes the camera's axis within a single pixel, making original images with very little waving and blurring, and fewer burdens for post-processing. The TLS principle brings line perspective images with very little distortion in the flight direction and is effective to generate seamless orthoimages especially for linear-shaped objects such as roads, rivers, etc. The system also measures the position and attitude data of the camera for each line image by GPS and IMU, which leads to fewer ground control points needed for the image orientation. The paper describes the system configuration of the STARIMAGER® developed by STARLABO Corporation, Tokyo, Japan, including the data processing system. It also refers to a variety of applications featuring the TLS principle.

1. Introduction

A line sensor system is widely used in a satellite for easy multi-spectral image acquisition, while an area sensor system is coming to the market, positioned as an extended form of a conventional analog aerial photo system. These two approaches have been intensively studied as an airborne fully-digital spatial data acquisition system. The line sensor system, however, is always ahead of the area sensor system because more pixels can be aligned in a CCD sensing device for the acquisition of a high-resolution image than the area sensor system due to the constraints of semiconductor manufacturing processes. This paper explains the system configuration, features and applications of a state-of-the-art helicopter-borne three-line scanner (TLS) system, STARIMAGER®, developed by STARLABO Corporation, Tokyo, Japan (see Figure 1).

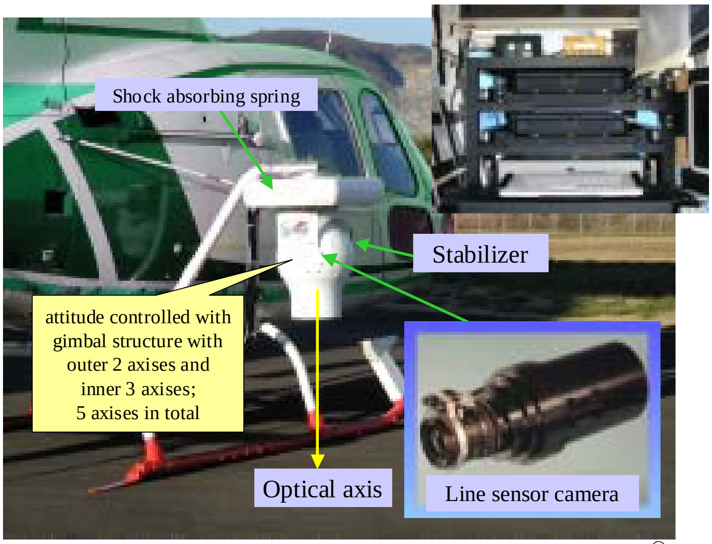


Figure 1. Three-Line Scanner - STARIMAGER®

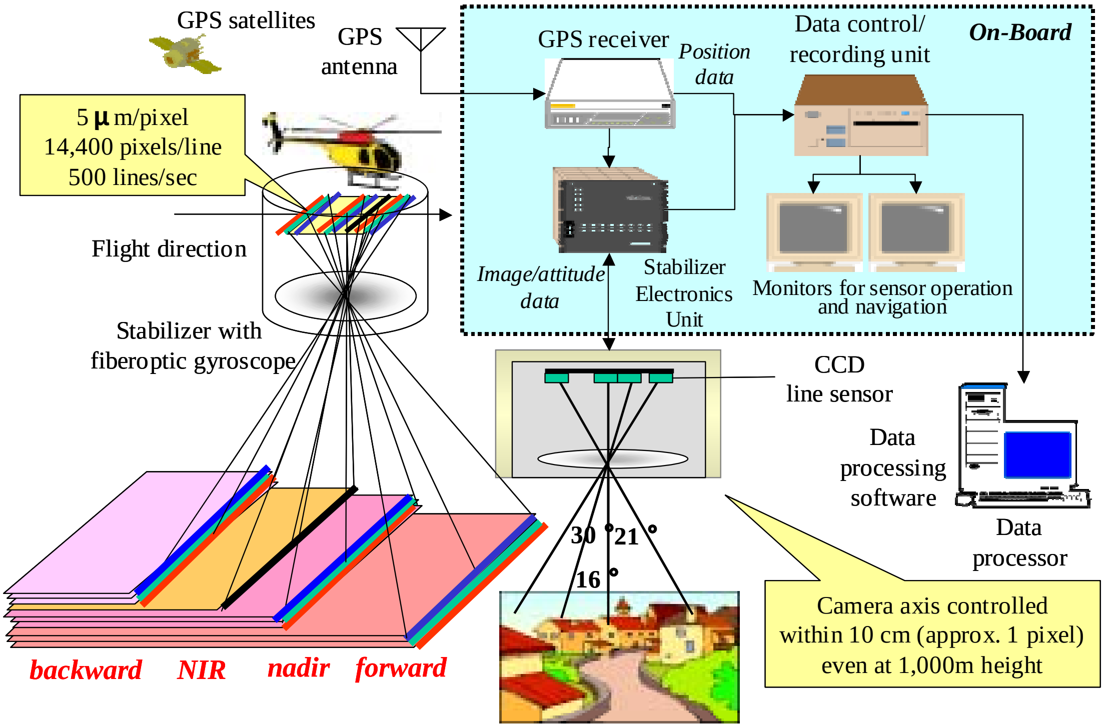


Figure 2. STARIMAGER® and its Principle

2. System Overview

2.1 Principle of STARIMAGER®

The stabilizer with the TLS camera is equipped on the arm outside a helicopter and absorbs the vibration by the helicopter movement. As shown in Figure 2, Four CCD line sensor packages are placed in parallel on the focal plane of the camera lens system as shown. The three out of those sensors are for forward-looking, nadir-looking and backward looking. Each sensor package has 3 lines which are R (Red), G (Green) and B (Blue) to generate a color image. In addition, there is another CCD line sensor package for near infra-red (NIR) image between one for the backward-looking and one for the nadir-looking. Each line sensor can get a high-resolution, two-dimensional image in accordance with the flight of the helicopter, bringing 10 images in total which are 100% overlapped with each other as shown in Figure 2. The position and attitude data of the TLS camera for each line image are acquired with GPS (Global Positioning System) and IMU (Inertial Measurement Unit). An antenna for the GPS is equipped at the top of the helicopter, while a set of fiber-optic gyroscopes is placed on the TLS camera within the stabilizer. Such spatial data acquisition system does not need aerial triangulation with ground control points, ideally in principle, at all as described in (Murai et al., 1004), (Murai et al., 2000) and (Murai 2001). STARLABO Corporation acquires the patent right for the system in Japan, the USA, Europe, Australia, and Canada as shown in (Murai et al., 1993).

2.2 Features of STARIMAGER® and Advantages

The advantages of STARIMAGER® are described as follows (also described in (Tsuno, 2002a) and (Tsuno 2002b).

1) Photograph developing and scanning processes are unnecessary and there is no image deformation of a film such as damage or deterioration. Moreover, since the dynamic range of an output image that is linearly proportional to the luminance of the image plane is wide, it is possible to recover easily even an image part that is in the shade of a building, a cloud, and so on by increasing its image intensity, which leads to the reduction of field survey after data acquisition.

2) The ground control points (GCPs) for the orientation can be unnecessary, or fewer due to the existence of a GPS/IMU. It is, therefore, suitable for data acquisition at emergency, on the sea, and so on, where GCPs are difficult to get.
3) Since, due to a high-performance stabilizer, an acquired original image is not waving and have no blurs, it is suitable for the image at emergency and the load for post-processing can be reduced. And, the oblique photography that is realized by slanting the stabilizer is effective in the texture acquisition of building walls (Figure 3).
4) A helicopter allows low altitude and low speed operation, leading to a high-resolution image (see Figure 4). Since an influence by field visibility and weather condition is small due to low altitude, photography can be done more frequently than a conventional aerial photography. And, it can take pictures of the linear-shaped objects efficiently by following it over at a low speed.
5) With the TLS principle, an image scale has very little distortion due to the height of objects in the flight direction (a line-perspective image as compared with a conventional central perspective image), and suitable for orthoimage generation. The system does not need mosaic processing in the flight direction without any scrapping parts and it can get the spatial data of linear-shaped objects seamlessly, such as roads, railroads, rivers, etc. Moreover, the system can get an image that is redundant and little loss due to the photography in 3 different directions (3 different times), leading to fewer field survey burdens after the data acquisition. Furthermore, a corresponding point searching in stereo matching is easy due to the stereo angles being constant, and measurement precision improves by triplet matching as simulated in (Shibasaki et al., 1987). It eases a multi-spectral data acquisition and allows getting a color image by integrating RGB three line sensor images and an NIR image as an index which shows vegetation and water in the soil more distinctively than a color image (see Figure 5).

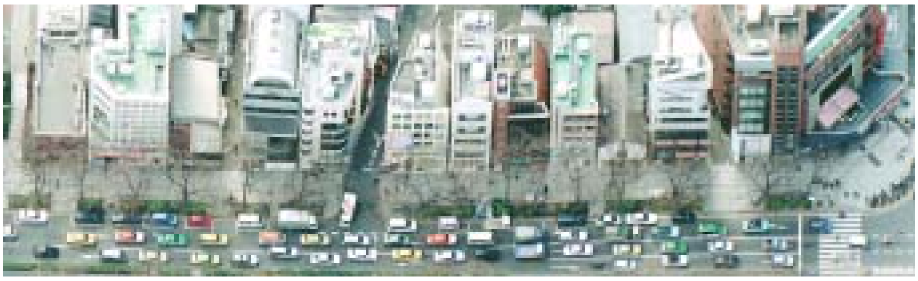
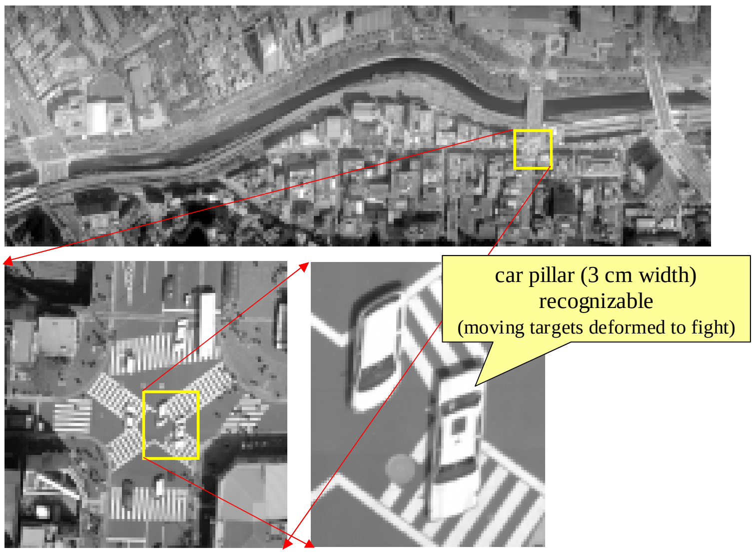


Figure 3. An Image Sample by Oblique Viewing



Ochanomizu on Chuo-line; 2001/4/17; height: 300 m; speed: 60 km/h; nadir

Figure 4. High Resolution TLS Image

Figure 5. Color Image (left) and NIR Image (right)
(The NIR image distinguishes more vegetation area – upper-middle - along the river than the color image.)

2.3 System Configuration of STARIMAGER® Photographic System

The focal distance of the TLS camera lens system is 60 mm, the stereo angles are 21, 30 and 51 degrees, between forward and nadir, nadir and backward, and forward and backward, respectively (see Figure 6 for the system specifications). Each line sensor consists of 14,400 CCD pixels with 5 μm spacing, and acquires 500 line images in 1 second (2 msec acquisition interval, and it is recorded in a controlling and recording device to install in the helicopter cabin. On the other hand, a GPS antenna acquires the camera position signal at 5 Hz and the IMU on the top of the TLS camera acquires the camera attitude signal at 500 Hz.

The stabilizer has a vibration absorbing spring and 5 gimbals, absorbs the shake of the helicopter, and keeps the optical axis direction of the TLS camera stable within a single pixel of the line sensor. Therefore, an image never waves due to the shake of the helicopter, and never be blurring as shown in Figure 7.

configuration	item		specification
TLS Camera	CCD Elements	pixels/line	14,400
		pixel pitch	5 μm
	Number of Sensors		10 (3 direction/RGB for each and NIR)
	Intensity dynamic range		11 bits or more
	Lens focal length		60 mm
	Stereo angle		21°, 30°, 51°, etc.
	Number of capturing lines		125, 250, and 500 lines/sec
Stabilizer	Angle resolution in attitude		0.00125°
	Spatial stability		0.00029°
	Maximum angle velocity		30°/sec
	Data output (acceleration/attitude)		500 Hz
GPS Receiver	2f kinematics (post processes)	planimetric accuracy	2 cm + 2 ppm
		height accuracy	3 cm + 2 ppm
	Data output		5 Hz
Recorder	HDD recording	recording speed	150 MB/sec or more
		recording capacity	320 GB

Figure 6. STARIAMGER Basic Specifications

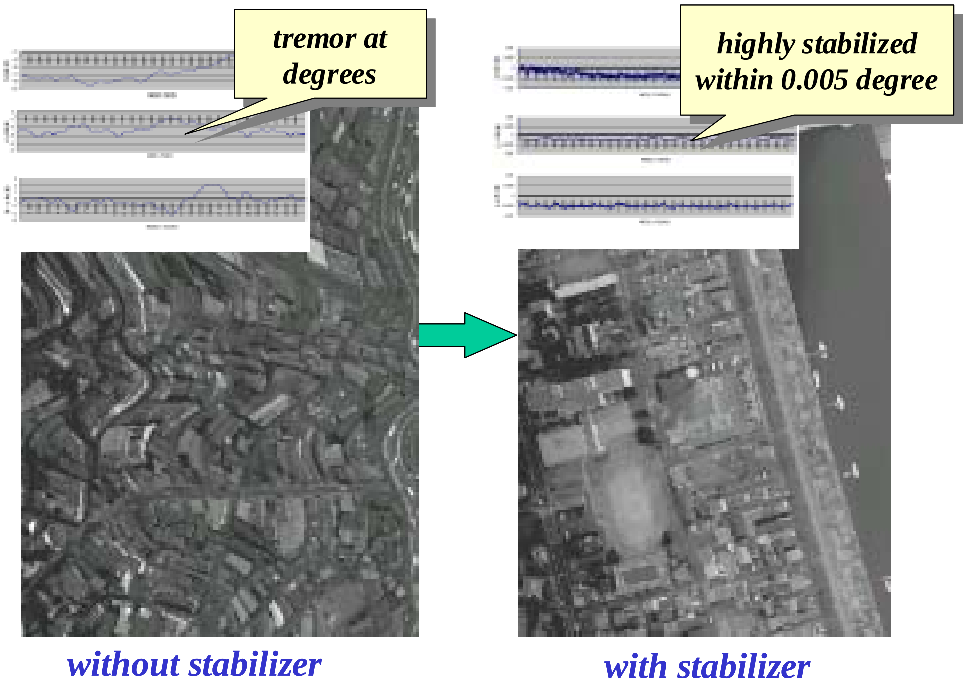


Figure 7. Stabilizer's Effect

2.4 Characteristics of TLS Data and Measurement

The swath width at the flight altitude of 400 m is approximately 480 m, the resolution on the ground (or ground sample distance; corresponding to a CCD pixel) perpendicular to the flight is 2.5cm. On the other hand, the resolution in the flight direction is determined by the flight speed and 2.5 cm resolution can be realized by flying at 60 km/h (to proceed by 2.5 cm for the standard image sampling period 2 msec.

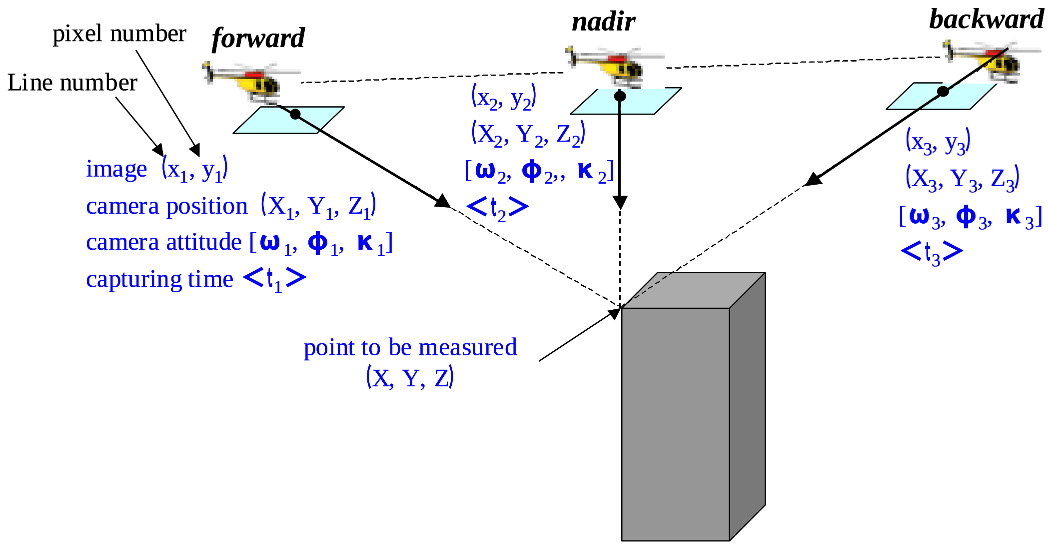


Figure 8. 3D Position Measurement

A point to be measured on the ground is, as shown in Figure 8, acquired by the forward-looking first, and then nadir looking and backward-looking, and recorded as a line image with each line and pixel number. And, since the position and attitude information of the TLS camera center for every line image is measured simultaneously, it is possible to get the point position information of three dimensions by forward intersection method. The aerial triangulation is applied to perform absolute orientation with better accuracy by using a number of GCP (ground control points) in consideration of the drift of the IMU signal and the restriction of the acquisition frequency of the GPS data. As a result, it can get 10 – 15 cm accuracy in a planimetric direction and 15 – 20 cm in a height direction at 500 m height as verified in (Chen et al., 2001) and (Morita et al., 2001) with the sufficient number of GCPs, which leads to the possibility of map with a large scale, such as 1/500 (with 25 cm RMS for both planimetric and height accuracy) or larger. It is an important issue to consider how to plan a set of flight courses and GCPs in order to meet an accuracy requirement. Figure 9 concludes that it is better to fly a target area with multiple courses as well as additional courses crossing the multiple courses to use fewer GCPs, where it is essential to get a reasonable number of tie-points (inter-strip) and pass-points (intra-strip) in and between course strips.

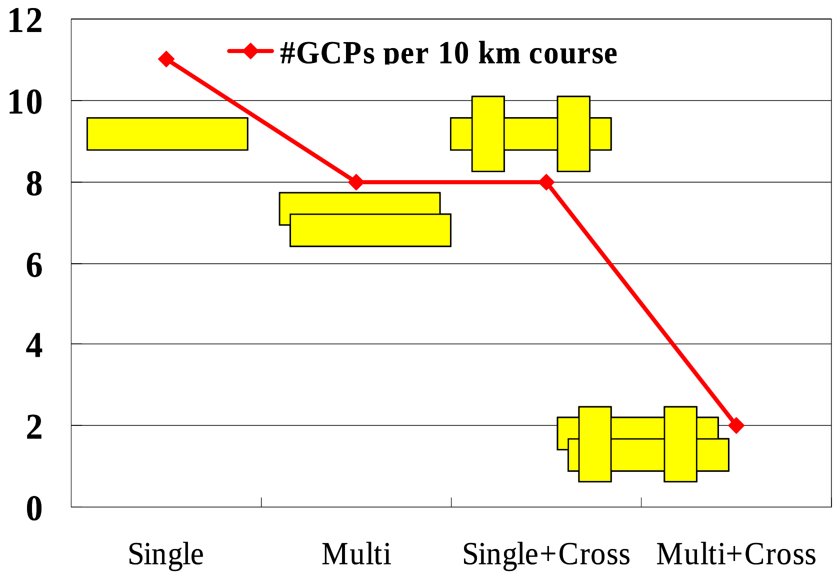


Figure 9. The Number of GCPs with 1/500 Map Accuracy

2.5 Overview of TLS Data Processing System

STARLABO Corporation has been developing the TLS data processing system with Pof. A. Gruen, ETH (Swiss Federal Institute of Technology, Zurich) and Prof. R. Shibasaki, the University of Tokyo. The system has realized functionality equivalent to existing digital photogrammetry system, such as aerial triangulation (see (Gruen et al., 2001), (Gruen et al., 2002a) and (Chen et al., 2003)), automated random altitude points extraction (see (Gruen et al., 2002b)), the generation of DEM data and an orthoimage, contour generation, the acquisition of polylines and the polygons, etc.

As described above, the TLS principle can eliminate photograph processes such as developing, image scanning and mosaickng in the flight direction as compared to the conventional aerial photograph. The reduction of the number of GCPs brings a significant amount of cost reduction in those survey processes, such as setting, measuring and tearing down of GCPs, and arrial triangulation. Moreover, an image with broader dynamic range, less distortion and occlusion (see Figure 10), and more redundancy reduce burdens for field survey.

2.6 Image GIS

It has been an issue to map and plot costly based on aerial photos to construct a GIS (Geographic Information System) system. A digital map may not be necessary to use from the very beginning to fulfill most of field applications. A new concept called, “Image GIS” has been presented to solve the issue. Figure 11 shows an example viewer materializing such a concept. An orthoimage goes as a background image for a 2D map that is obtained from another source and allows one to measure distances and areas on it. In addition, the Image GIS viewer is facilitated with a mono-image measurement system, where, as the center of the orthoimage moves, the target image for the measurement system moves. When one wants to measure the 3D position of a point precisely by pointing to it on the orthoimage, the viewer brings one with its corresponding image set (forward, nadir and backward) for the 3D measurement. In doing so, one can grasp a real 3D situation surrounding an underlying target object without going to an actual spot and then store the 3D data into a database attached to the GIS viewer.

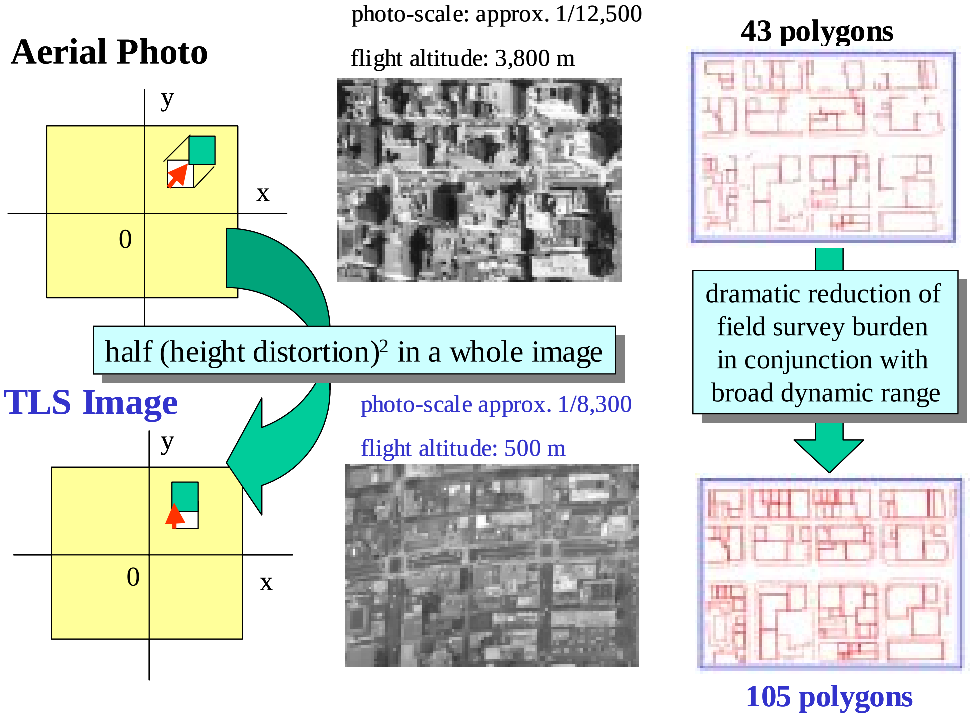


Figure 10. Image with Less Distortion

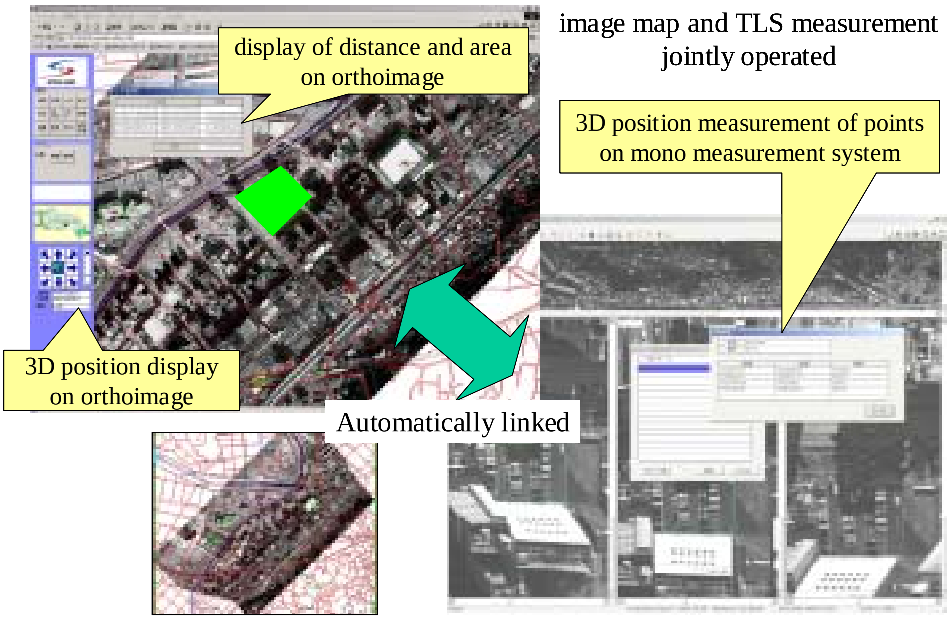


Figure 11. Image GIS Viewer

3. Applications of TLS

The features of the TLS data are stimulating more demands for 3D seamless information of linear-shaped man-made objects and terrain with high resolution and efficiency. Linear-shaped man-made objects include roads, bridges, railroads, power cables, pipelines, etc. for investigation before the construction of those, maintenance and management after the construction, and base data for a variety of GIS's. Figure 12 is an example of river, and can be used for the investigation of vegetation, the gravel grain diameter distribution of a dry riverbed, the river floor profile, and so on as described in (Fukami et al., 2002).

It also can be applied for the base ground data for flooding simulation with high precision that can judge whether water goes over a Japanese raised floor or below, which can not be judged based on conventional 50 m-meshed terrain data (see Figure 13). Three-dimensional city models with high definition, which is expected to use for city planning, landscape simulation, auto-navigation, gaming and so on. When the helicopter flies over along a road, wall texture facing the road can be acquired with a nadir-looking image. The wall textures that are perpendicular to the road can be acquired with either forward-looking or backward-looking image. Textures can be semi-automatically mapped onto 3D polygons. The acquisition of the texture of the building walls facing a trunk road also can be efficiently acquired with oblique-viewing image. An web-site application with those TLS images is realized as shown in Figure 14.

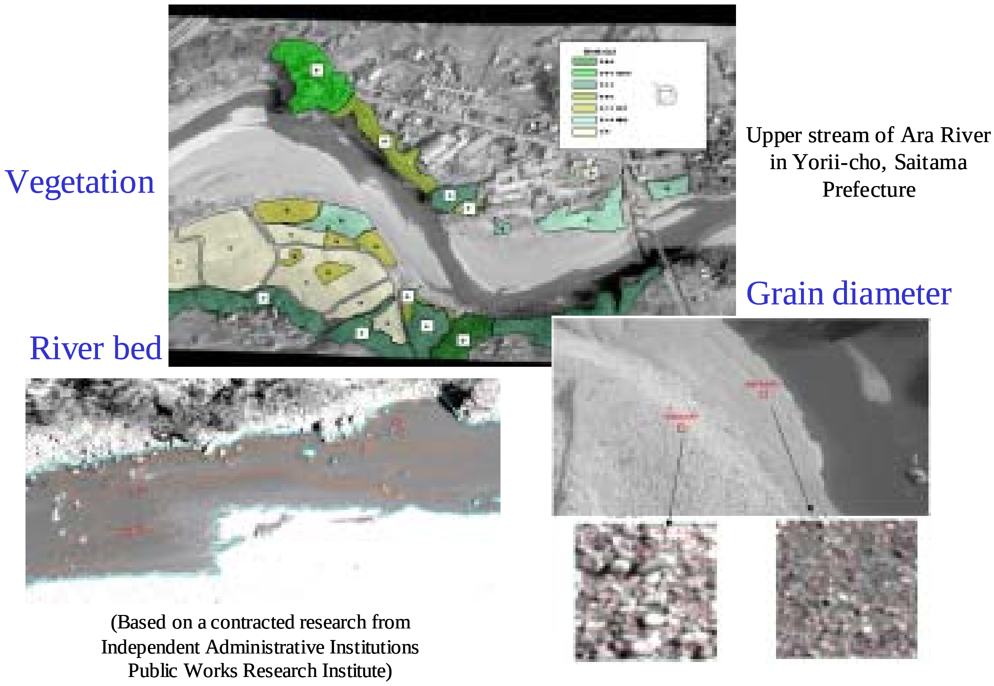


Figure 12. Survey for River Environment

Figure 13. Flooding Simulation

Figure 14. An Example for Web Contents

Figure 15 is an example of perfect orthoimages (TrueOrtho™) where the TLS data is taken with highly overlapped between courses and processed with the cooperation of ISTAR in France. A conventional orthoimage has leaning buildings with its sidewalls which occlude roads because the image is generated based on the terrain data only, while a perfect orthoimage is made based on the height of buildings as well. Consequently, it is useful to avoid mistakenly digging in case of construction because the position of gas or water pipes under roads can be well described with high precision and reality.

Furthermore, using the characteristics that can acquire an image of three directions in the constant time lag, the systems can measure the speed of a car, running water, etc. And, it can be applied to the traffic flow measurement which goes along a road and illegal parking investigation judging from the image deformation of a car, a distance from a road edge, etc.

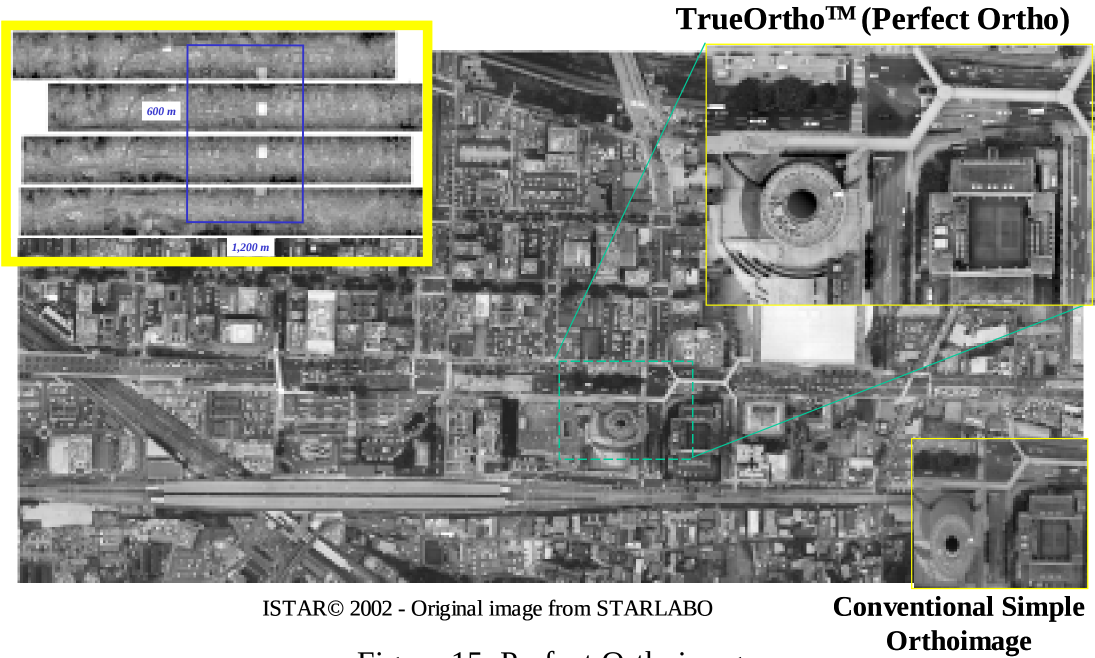


Figure 15. Perfect Orthoimage

4. Conclusion

A day when a conventional spatial data acquisition tool based on aerial photographs is substituted with TLS will come soon. The paper presented the principle of TLS and its applications at an early stage. The biggest issue is to improve the measurement accuracy of position and attitude of the TLS camera center by the GPS/IMU for higher accuracy measurement that needs as few GCPs as possible. Furthermore, the extraction of changes between images of two different times, automatic extraction of man-made objects such as buildings and roads (as described in (Nakagawa et al., 2001)), and speed measurement of cars and rivers should be studied.

Acknowledgement

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References

(Chen et al., 2001) Tianen Chen, Ryosuke Shibasaki, and Kazuya Morita, "Development and calibration of airborne three-line scanner (TLS) imaging system," 3rd International Image Sensing Seminar ISPRS, Sep. 2001.

(Chen at al., 2003) Tianen Chen, Ryosuke Shibasaki and Shunji Murai, "Development and calibration of the airborne three-line scanner (TLS) imaging system," Photogrammetric Engineering & Remote Sensing, Vol. 69, No. 1, January 2003, pp. 71 – 78.

(Fukami wt al., 2002) Kazuhiko Fukami, Takuya Okada and Jun-ichi Yoshitani: "A study on an information collection method for river blocks with TLS," JSPRS Conference, J-4，2002.7，pp. 185 – 188.

(Gruen et al., 2001) Armin Gruen and Li Zhang: "TLS Data Processing," 3rd International Image Sensing Seminar ISPRS, Sep. 2001.

(Gruen et al., 2002a) Armin Gruen and Li Zhang: "Sensor modelling for aerial mobile mapping with three-line scanner (TLS) imagery," Int. Arch. of Photogrammetry and Remote Sensing, Vol. 34, Part 2, 2002, pp. 139-146.

(Gruen et al., 2002b) Armin Gruen and Li Zhang: "Automatic DTM generation from three-line scanner (TLS) Images. Int. Arch. of Photogrammetry and Remote Sensing," Vol. 34, Part 3A, 2002, pp. 131-137.

(Morita et al., 2001) Kazuya Morita, Ryosuke Shibasaki, Tianen Chen, Bokuro Urabe and Mayumi Noguchi: "Accuracy evaluation of aircraft-borne photographic device," JSPRS Conference Fall 2001，2001.11.

(Murai, 2001) Shunji Murai: "Digital photogrammetry without any ground control points," Zensokuren, Spring 2001，pp. 15 – 20.

(Murai et al., 1994) Shunji Murai and Yoshitama Matsu: "3D measurement with three-line scanner (TLS)，Photogrammetry and Remote Sensing," vol. 33，No. 5，1994，pp. 21 – 25.

(Murai et al., 2000) Shunji Murai and Yoshifumi Yasuoka: "Earth industry and space industry," Industrial Sciences，vol. 52, No. 3, 2000.3，pp. 38 – 42.

(Murai et. al, 1993) Shunji Murai et al., Patent 02807622: "Airborne photographic apparatus," 1993.12.

(Nakagawa et al., 2001) Masafumi Nakagawa, Ryosuke Sshibasaki: "Study on making 3D urban model with TLS image and laser range data," Asian Conference on Remote Sensing, November 2001

(Shibasaki et al., 1987) Ryosuke Shibasaki and Shunji Murai: "A simulation on improvement of the accuracy and the stability of stereo matching using triplet linear array sensor data"，Photogrammetry and Remote Sensing，vol. 26，No. 2，1987 pp. 4 – 10.

(Tsuno, 2002a) Koichi Tsuno: "Practices in spatial information technology: Three-line scanner and its applications," JSPRS 2002.

(Tsuno 2002b) Koichi Tsuno: "Three-line scanner and its applications," Photogrammetry and Remote Sensing，Vol. 41，No. 4，2002 pp. 37 – 40.